CASE 57

New Ultraminiature KMS Tact Switch Optimization

Abstract: A robust design effort was initiated using Taguchi's dynamic parameter design approach. An L_{18} orthogonal array was used to evaluate the control factors with respect to the signal factor (dome travel), the response (actuating force), and the noise factors (process and material variations and number of operational cycles). The numerical experiments were carried out by using computer simulations only. The signal-to-noise ratio increased 48.7 dB as a result of this optimization. The analysis and selection of the best system parameters confirmed the process estimates and resulted in a design with dramatically improved mechanical and reliability performance.

1. Introduction

The newest multifunction switch at ITT Cannon, the KMS switch, was designed specifically to meet phone market requirements. This switch is a new type of ultraminiature tact switch (Figure 1).

An engineering team was created to address the switch design and to improve its mechanical and electrical performances. A parameter design approach was selected using the method of maximizing the SN ratio and of optimizing the forces and the tactile feel.

The essence of the switch is the K2000 dome (Figure 2). The dome provides the spring force, the tactile feel, and the electrical contact. A properly designed dome functions in a unique manner: As the dome is compressed, a point is reached where the actuating force actually declines and goes through a minimum value. The person actuating the switch feels the change in force, so it is called a *tactile feel*. The tactile feel is usually quantified by the ratio of actuating force to forward force (Figure 3).

2. Background

The KMS switch uses a very small dome with the following specifications:

- ❑ Ultraminiature dimensions: 1.7 × 2.8 mm
- ❑ Actuating force, F_a
- ❑ Forward force, F_{ra}
- ❑ Maximum tactile feel, given by the ratio $(F_a - F_{ra})/F_a$ (see Figure 3)
- ❑ Operation life of 300 K_{op}/min.

3. Objectives

The objective of the parameter design effort using Taguchi's approach was to determine a set of design parameters that would result in the largest number of operating cycles while keeping a good tactile feel and a constant actuating force for the life of the product. The function of the switch is to give a tactile feel at a predetermined actuating force and to transmit an electrical current when it is actuated during the life of the product. This can be described using the force–deflection (F/D) curve (Figure 3). The ideal switch would exhibit an F/D curve that would not change during the life of the product.

The analytical objective for Taguchi's parameter design approach is to maximize the SN ratio. The SN ratio is a metric that measures the switch

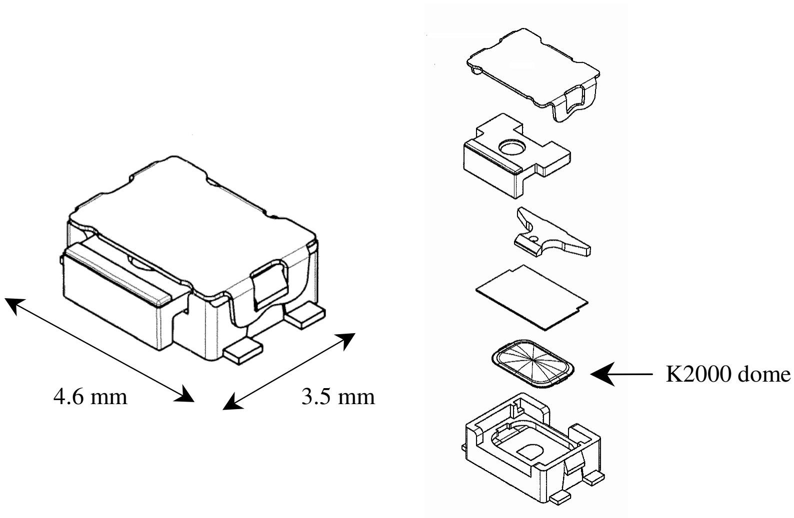

Figure 1
KMS tact switch

function when exposed to external factors, called noise factors, which may affect that performance. As the effect of these noise factors increases, the SN ratio decreases. The performance of the switch is measured while being exposed to these noise factors for various combinations of design parameters, using an orthogonal array to provide a balanced treatment of these control factors to the noise factors. The performance characteristics measured were the typical points of the F/D curve and specifically the actuating force F_a (M_1) and the forward force F_{ra} (M_2).

4. Finite-Element Analysis (Computer Simulations)

All the experiments in this study are numerical experiments that were conducted by using computer simulation (finite-element analysis). A different F/D curve was calculated for each combination of factors. The aging effect (due to the number of operations) corresponding to each dome design was obtained from the calculated maximum stress level by using a modelization of the Wöhler curve (Figure 4).

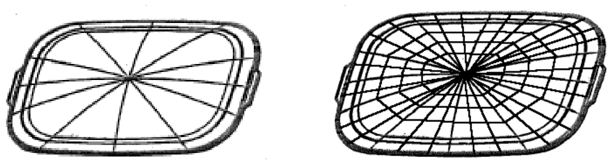

Figure 2
K2000 dome

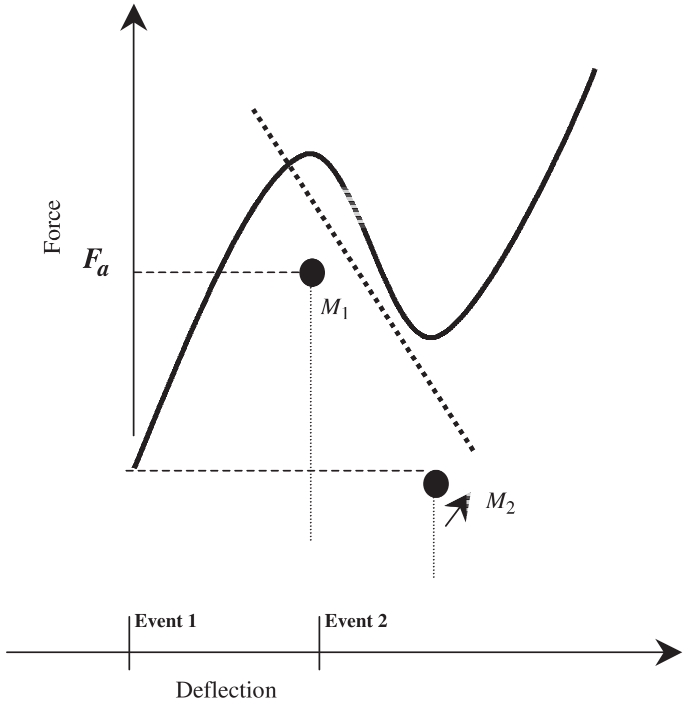

Figure 3
F/D curve for electromechanical switch

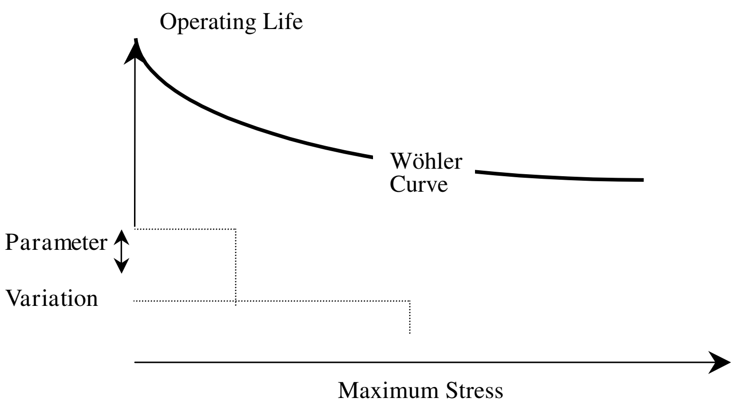

Figure 4
Operating life obtained from the Wöhler curve

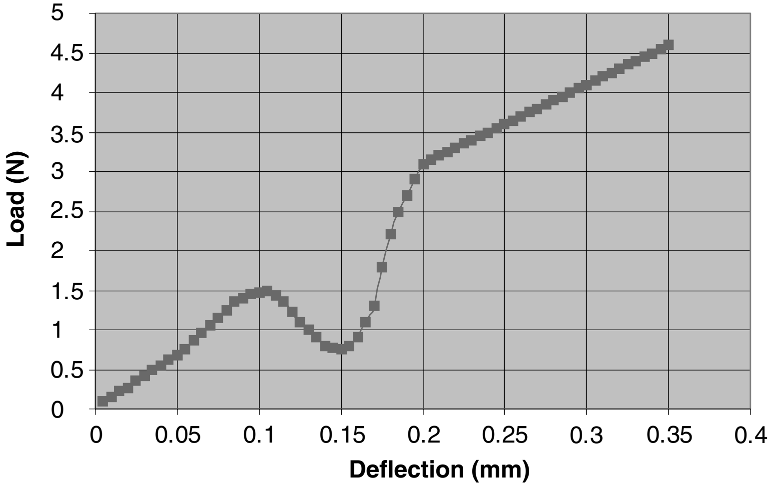

Figure 5
Ideal F/D curve

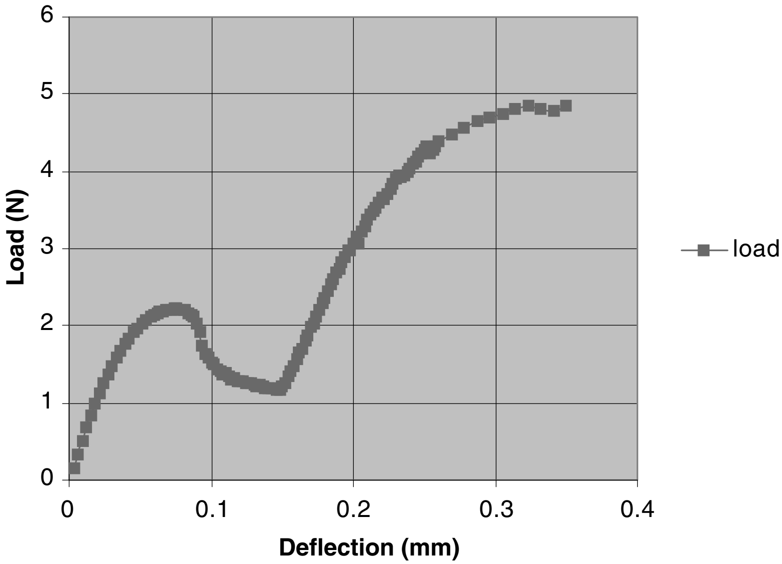

Figure 6
Simulated F/D curve (corresponding to one design)

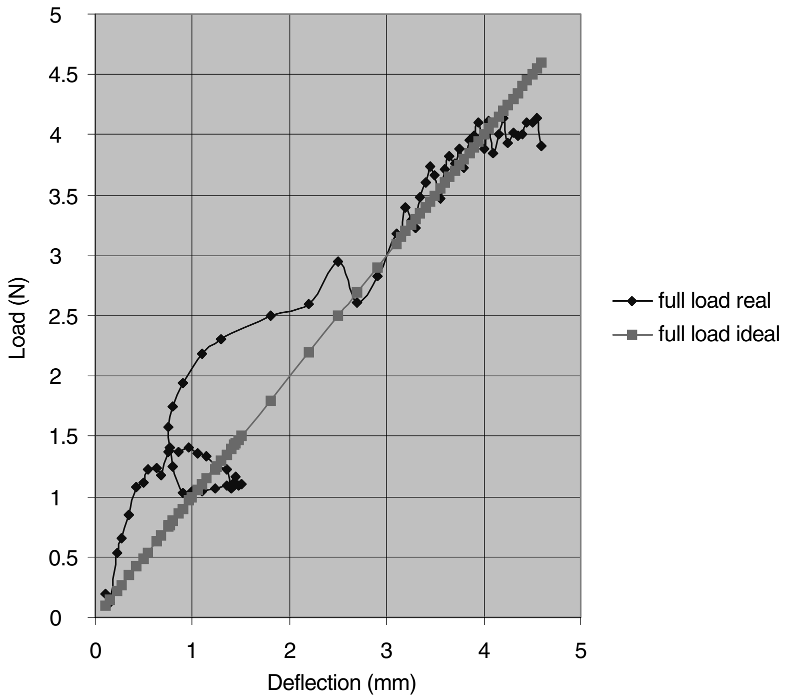

Figure 7
Simulated F/D curve versus the ideal switch F/D curve

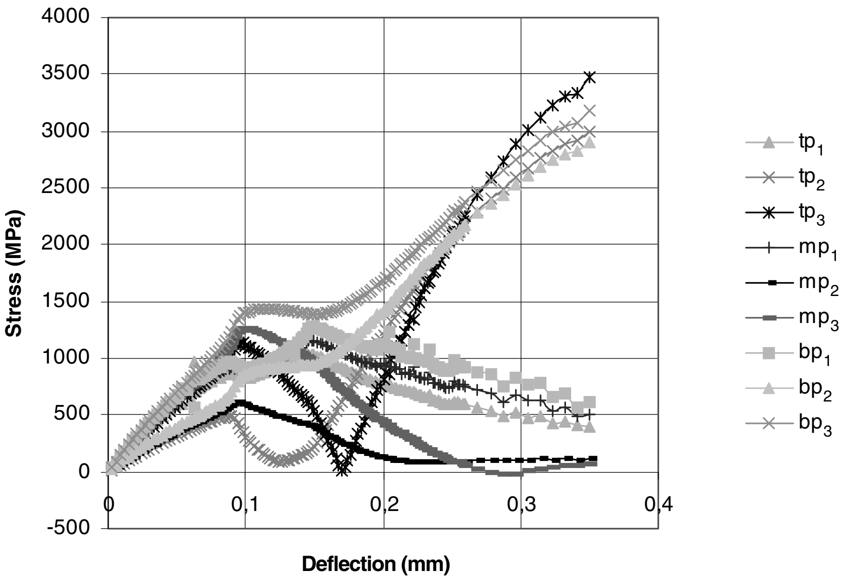

Figure 8
Stress curves at different points of the dome (corresponding to one dome design)

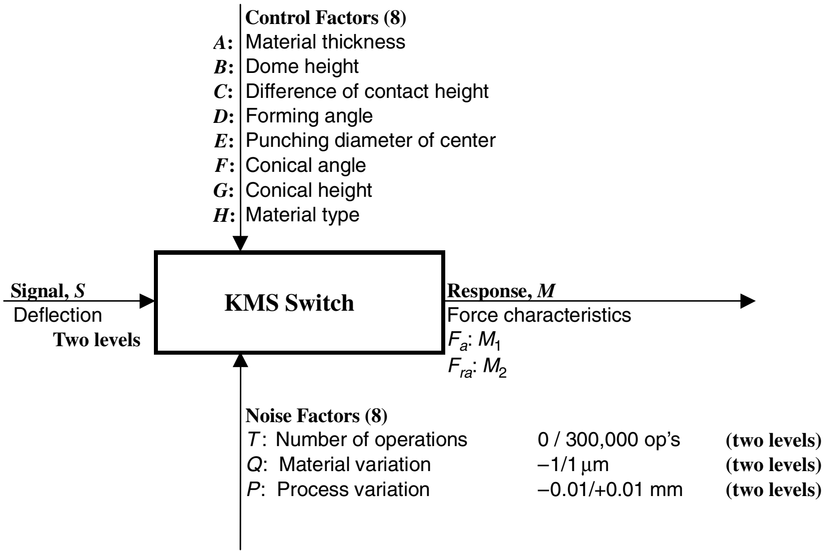

Figure 9
P-diagram

	M_1								M_2							
T	1	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
Q	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
P	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8

No.	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1	1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2	1
3	1	3	3	3	3	3	3	1
4	2	1	1	2	2	3	3	1
5	2	2	2	3	3	1	1	1
6	2	3	3	1	1	2	2	1
7	3	1	2	1	3	2	3	1
8	3	2	3	2	1	3	1	1
9	3	3	1	3	2	1	2	1
10	1	1	3	3	2	2	1	2
11	1	2	1	1	3	3	2	2
12	1	3	2	2	1	1	3	2
13	2	1	2	3	1	3	2	2
14	2	2	3	1	2	1	3	2
15	2	3	1	2	3	2	1	2
16	3	1	3	2	3	1	2	2
17	3	2	1	3	1	2	3	2
18	3	3	2	1	2	3	1	2

Force Characteristics (N)

Figure 10
Experimental layout showing L_{18} and outer group

Table 1
Control factors and levels

Control Factor		Level 1	Level 2	Level 3
A:	material thickness (μm)	30	35	38
B:	dome height (mm)	0.12	0.15	0.2
C:	difference of contact height (mm)	0	0.05	0.1
D:	forming profile (three-dimensional)	1	2	3
E:	punching diameter/depth of center area (mm)	0/0	0.25/0.025	0.5/0.05
F:	conical angle (deg)	12.5	25	40
G:	conical height (mm)	0.02	0.05	0.1
H:	material type	1	2	

We obtain the following charts:

- The ideal F/D function (Figure 5)
- One example of F/D curve obtained by computer simulation (Figure 6)
- The F/D curve of Figure 6 versus the ideal F/D curve (Figure 7)
- One example of stress curves at different points versus dome deflection (Figure 8)

5. P-Diagram

The switch product, generally called an engineered system, can be described by a visual method called a P-diagram. This diagram indicates the relationship between parameter types and the input and outputs of the switch system. The dome deflection is the signal. Figure 9 presents the P-diagram for the KMS switch system. The control factors are selectable by the designer, but the noise factors are not, except when they are controlled to evaluate their impact on the system. The typical response points are, respectively, the actuating force F_a (M_1) and the forward force F_{ra} (M_2).

Table 2
Noise factors and levels

Noise Factor		Level 1	Level 2
N:	material variation (μm)	−1	1
P:	process variation	−0.01	0.01
T:	number of operations (K_{op})	0	300

6. Experimental Layout

The factors shown in Figure 9 were assigned to an experimental layout consisting of an L_{18} orthogonal array and a full-factorial combination of the signal and noise factors (Figure 10).

The factors and their associated levels are described in Table 1. The control factors were assigned to the columns of the orthogonal array with the coefficients in the column representing the level of the corresponding factor. The noise factors were assigned to the outer, fully orthogonal group (Table 2).

7. Results and Analysis

Figure 11 presents the results from the computer simulations done by finite element analysis. For

	M_1 (F_a: actuating force)								M_2 (F_{ra}: forward force)																	
	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2										
	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2										
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2										
No.	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	S_M	S_N	V_M	V_N	S_T	S_{NxM}	$V_{N'}$	SN	10 log V_M	10 log V_m
1	1.40	1.60	1.95	2.20	1.27	1.41	1.44	1.86	1.10	1.30	1.00	1.20	1.01	1.16	0.83	1.06	1.25	0.53	1.25	0.08	2.15	0.366	**0.06**	**12.90**	**0.96**	**14.72**
2	2.10	2.20	2.75	3.15	1.14	1.18	0.95	0.90	1.60	2.00	1.55	1.90	0.94	1.10	0.71	0.71	0.93	6.41	0.93	0.92	8.13	0.79	**0.51**	**2.57**	**−0.32**	**15.87**
3	2.95	3.80	3.85	4.40	0.50	0.50	0.50	0.50	2.90	3.80	2.95	3.60	0.50	0.50	0.50	0.50	0.19	38.11	0.19	5.44	38.83	0.53	**2.76**	**−11.59**	**−7.18**	**18.13**
4	3.60	4.00	4.00	4.20	2.52	2.78	2.08	2.35	3.61	4.01	4.01	4.21	2.53	2.79	2.09	2.36	0.00	10.15	0.00	1.45	10.15	0.00	**0.73**	**−32.58**	**−33.98**	**22.13**
5	3.90	4.50	5.40	6.00	1.44	1.50	1.85	1.88	2.20	2.30	2.40	2.20	0.97	0.95	1.02	0.93	11.38	22.56	11.38	3.22	39.19	5.26	**1.99**	**7.58**	**10.56**	**19.87**
6	4.30	4.95	5.35	6.00	0.50	0.50	0.50	0.50	2.10	2.90	4.90	5.35	0.50	0.50	0.50	0.50	1.79	70.98	1.79	10.14	75.82	3.04	**5.29**	**−4.71**	**2.53**	**19.97**
7	6.00	6.60	6.00	7.00	2.84	2.94	2.15	2.13	6.01	6.61	6.01	7.01	2.85	2.95	2.16	2.14	0.00	63.01	0.00	9.00	63.01	0.00	**4.50**	**−40.51**	**−33.98**	**25.03**
8	3.20	3.75	4.35	4.40	0.50	0.50	0.50	0.50	2.70	3.20	2.60	2.55	0.50	0.50	0.50	0.50	1.35	32.76	1.35	4.68	36.28	2.17	**2.49**	**−2.66**	**1.31**	**17.72**
9	6.90	7.80	7.70	8.50	1.14	0.87	0.86	0.50	4.40	6.95	7.20	8.20	0.89	0.82	0.84	0.50	1.25	172.00	1.25	24.57	175.69	2.44	**12.46**	**−10.00**	**0.96**	**24.09**
10	1.80	2.10	2.15	2.40	0.86	0.82	0.91	0.79	1.80	2.10	1.65	2.20	0.86	0.82	0.79	0.76	0.05	6.07	0.05	0.87	6.22	0.11	**0.44**	**−9.85**	**−13.40**	**15.12**
11	1.90	2.05	2.70	3.00	1.20	1.28	1.71	1.25	1.90	2.00	1.70	2.05	1.20	1.25	1.16	0.97	0.51	3.88	0.51	0.55	5.02	0.63	**0.32**	**2.01**	**−2.91**	**16.69**
12	4.20	4.80	4.50	5.15	2.17	1.58	0.90	0.73	3.30	0.95	3.95	4.50	1.76	0.61	0.85	0.70	3.43	36.34	3.43	5.19	45.06	5.30	**2.97**	**0.62**	**5.35**	**20.14**
13	4.00	4.30	4.00	4.60	1.73	1.64	1.38	0.71	4.01	4.31	4.01	4.61	1.74	1.65	1.39	0.72	0.00	34.58	0.00	4.94	34.58	0.00	**2.47**	**−37.91**	**−33.98**	**20.98**
14	3.40	3.90	4.60	5.10	1.08	0.93	0.50	0.50	2.30	2.80	4.00	4.50	0.86	0.79	0.50	0.50	0.88	43.96	0.88	6.28	45.56	0.72	**3.19**	**−5.58**	**−0.54**	**19.15**
15	8.00	6.10	6.05	7.40	1.63	0.50	0.50	0.50	4.00	5.00	3.20	1.50	1.03	0.50	0.50	0.50	13.05	83.53	13.05	11.93	113.78	17.20	**7.19**	**2.59**	**11.16**	**21.38**
16	3.10	3.70	3.00	3.45	0.76	0.58	1.13	0.50	3.10	3.70	2.95	3.40	0.76	0.58	1.11	0.50	0.00	27.32	0.00	3.90	27.32	0.00	**1.95**	**−33.92**	**−31.02**	**18.15**
17	5.40	6.00	4.70	6.00	2.22	2.15	0.92	1.19	5.41	6.01	4.71	6.01	2.23	2.16	0.93	1.20	0.00	65.97	0.00	9.42	65.97	0.00	**4.71**	**−40.71**	**−33.98**	**23.11**
18	5.30	6.00	6.35	7.00	0.50	0.50	0.50	0.50	4.90	2.40	4.80	1.90	0.50	0.50	0.50	0.50	7.09	77.38	7.09	11.05	98.14	13.68	**6.50**	**0.37**	**8.51**	**20.56**

Figure 11
Numerical results

Table 3
ANOVA for the SN ratio

Source	Pool	d.f.	S	V	F	S'	R
A		2	1286.0658	643.0329	80.2653	1270.0431	23.84
B		2	1413.2788	706.6394	88.2049	1397.2561	26.22
C		2	0.5300	0.2650			
D		2	376.9884	188.4942	23.5284	360.9657	6.77
E		2	36.5609	18.2804			
F		2	380.5481	190.2740	23.7506	364.5254	6.84
G		2	1718.4728	859.2364	107.2525	1702.4501	31.95
H		1	104.5913	104.5913	13.0554	96.5800	1.81
HA		2	10.9772	5.4886			
e_1							
e_2							
(e)		6	48.0681	8.0113		136.1928	2.56
Total		17	5328.0132	313.4125			

(e) is pooled error.

each line of the design of experiment, the ANOVA decomposition can be carried out as follows:

Source	d.f.	S	V
m	1	S_m	$V_m = S_m$
M	1	S_M	$V_M = S_M$
N	7	S_N	$V_N = S_N/7$
MN	7	S_{MN}	$V_{MN} = S_{MN}/7$
	16		

To optimize the system, Taguchi recommended that we use the following data transformations. This is a two-step optimization process:

1. *Signal-to-noise ratio:*

$$\mathrm{SN} = 10 \log \frac{V_M}{V_{N'}}$$

where $V_{N'} = (S_N + S_{MN})/14$.

2. *Sensitivity:*

$$S_M = 10 \log V_M$$

to maximize the delta of the force difference that plays on the tactile feel $(F_a - F_{ra})/F_a$

$$S = 10 \log V_m$$

to optimize the actuation force (F_a)

The SN ratio had to be maximized first. The sensitivity, S_M, had to be maximized next, and last, the S parameter had to be optimized to focus on the nominal force value. The data transformations resulted in the ANOVA tables and response graphs shown in Tables 3 to 5 and Figures 12 to 14.

1. *Signal-to-noise:* $10 \log(V_M/V_{N'})$ transformation (Table 3 and Figure 12)
2. *Sensitivity 1:* $S_M = 10 \log V_M$ transformation (Table 4 and Figure 13)
3. *Sensitivity 2:* $S = 10 \log V_m$ transformation (Table 5 and Figure 14)

Table 6 summarizes the results and the best level choice.

8. Confirmation

Table 7 presents a comparison of process estimates calculated from the numerical results and the confirmation values obtained from actual switch under

Table 4
ANOVA for 10 log V_M

Source	Pool	d.f.	S	V	F	S′	r
A		2	424.8138	212.4069	9.4948	380.0722	7.73
B		2	2461.2643	1230.6322	55.0106	2416.5227	49.13
C		2	16.8809	8.4404			
D		2	223.2589	111.6294	4.9900	178.5172	3.63
E		2	33.0715	16.5358			
F		2	328.7046	164.3523	7.3467	283.9630	5.77
G		2	1323.5088	661.7544	29.5812	1278.7672	26.00
H		1	55.7912	55.7912			
HA		2	50.8520	25.4260			
e_1							
e_2							
(e)		7	156.5957	22.3708		380.3037	7.73
Total		17	4918.1461	289.3027			

(*e*) is pooled error.

Table 5
ANOVA for 10 log V_M

Source	Pool	d.f.	S	V	F	S′	r
A		2	73.9262	36.9631	39.6632	72.0624	48.30
B		2	12.2648	6.1324	6.5804	10.4010	6.97
C		2	21.9876	10.9938	11.7969	20.1238	13.49
D		2	3.4679	1.7339			
E		2	0.6887	0.3444			
F		2	2.0802	1.0401			
G		2	28.8232	14.4116	15.4643	26.9594	18.07
H		1	0.2866	0.2866			
HA		2	5.6751	2.8376	3.0448	3.8113	2.55
e_1							
e_2							
(e)		7	6.5235	0.9319		15.8427	10.62
Total		17	149.2005	8.7765			

(*e*) is pooled error.

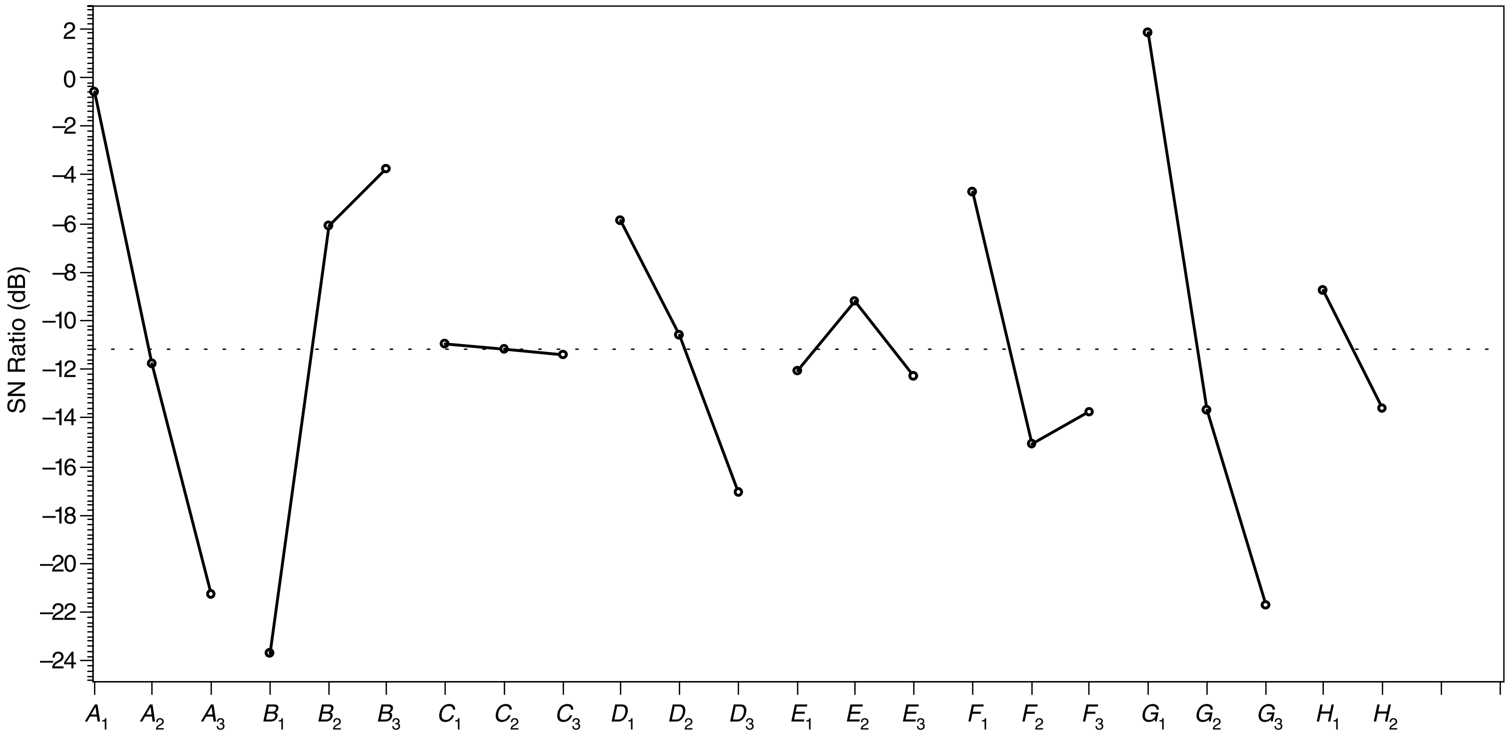

Figure 12
Response graph for the SN ratio

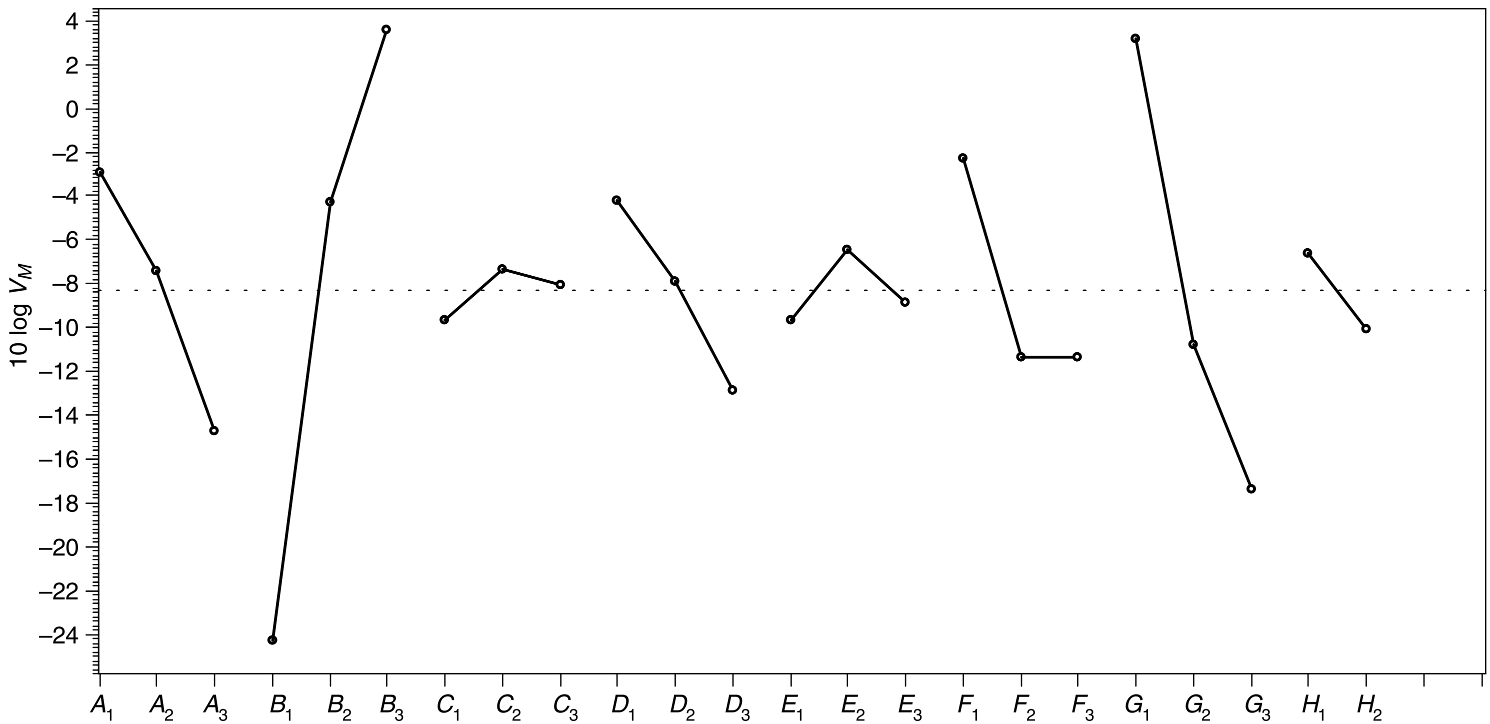

Figure 13
Response graph for 10 log V_M

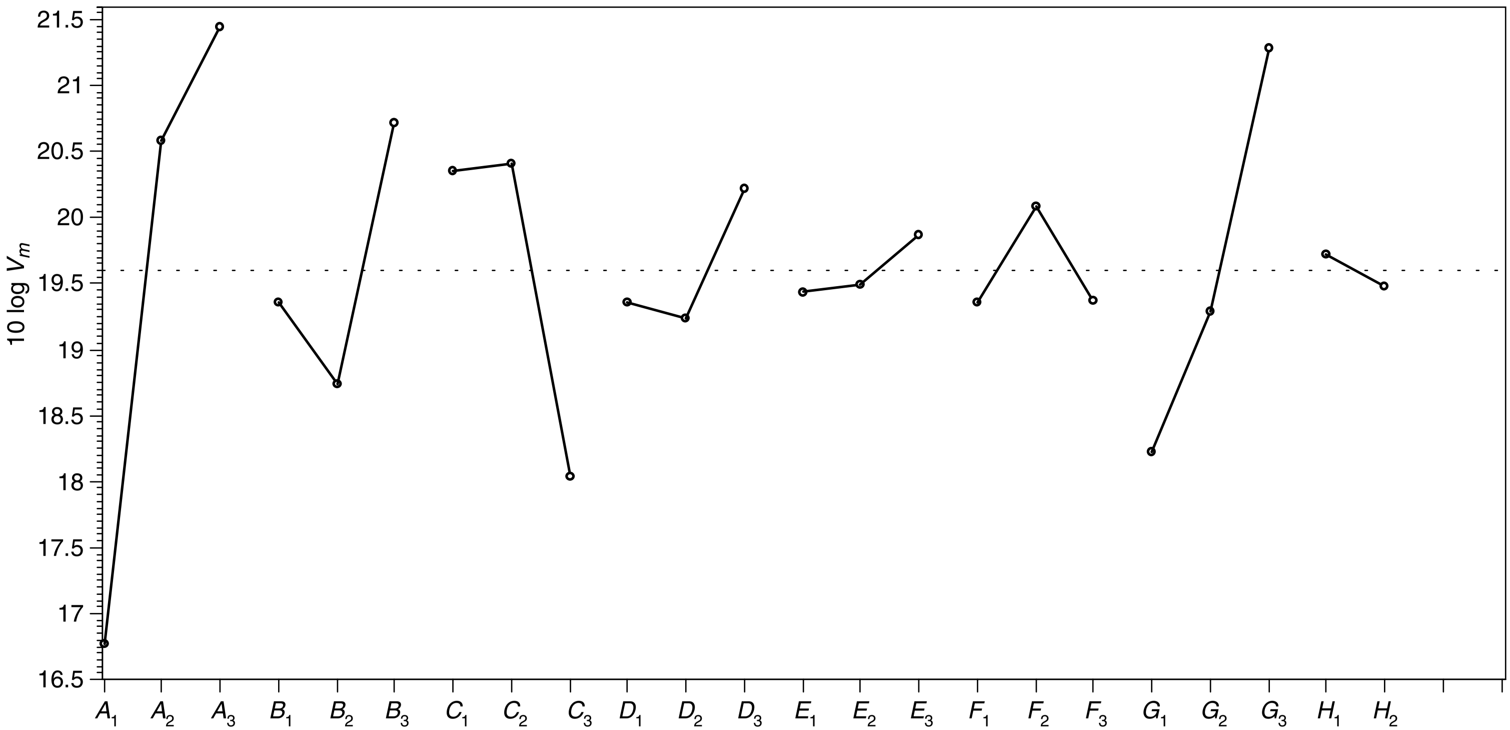

Figure 14
Response graph for 10 log V_m

Table 6
Best-level-choice table

	SN						
	10 log ($V_M/V_{N'}$)		10 log V_M		10 log V_M		
Factor	r (%)	Best Level	r (%)	Best Level	r (%)	Best Level	Best Choice
A	23.84	A_1	7.73	A_1	48.30	A_3	A_1
B	26.22	B_3	49.13	B_3	6.97	B_3	B_3
C					13.49	C_2	C_2
D	6.77	D_1	3.63	D_1			D_1
E							E_1
F	6.84	F_1	5.77	F_1			F_1
G	31.95	G_1	26.00	G_1	18.07	G_3	G_1
H	1.81	H_1					H_1

standard and optimized conditions. The SN ratio and 10 log V_M (difference between actuating and forward forces) increased, respectively, by 48.7 and 37.1 dB as the result of study. In addition, the average force calculated from S_m is 1.67 N, that is, fully in the specification range.

We made prototypes starting from the results of this study. Different batches of KMS switches have been tested, and very good operating life has been obtained (between 300 and 500 K_{op}). The experimental analysis and selection of the best system parameters confirmed the process estimates and resulted in a switch design with dramatically improved mechanical performances.

9. Conclusions

This study was carried out using only computer simulations, to decrease the development costs and time, but an experimental confirmation was made and was positive. The designs for the switch and manufacturing equipment have been made accord-

Table 7
Comparison of process average estimates and confirmation values

Parameter Set	Process Estimates	Confirmation Values
Initial product	SN = −20.4 dB 10 log V_M = −8.5 dB 10 log V_m = 23.7 dB	SN = −20.4 dB 10 log V_M = −8.5 dB 10 log V_m = 23.7 dB
Optimized product	SN = 33.0 dB 10 log V_M = 32.0 dB 10 log V_m = 16.8 dB	SN = 28.3 dB 10 log V_M = 28.6 dB 10 log V_m = 16.5 dB
Improvement	ΔSN = +53.4 dB Δ10 log V_M = +40.5 dB Δ10 log V_m = −6.9 dB	ΔSN = +48.7 dB Δ10 log V_M = +37.1 dB Δ10 log V_m = −7.2 dB

ingly as a result of the confirmation of this parameter design effort. The right key characteristics have been reached directly (actuating force, tactile feel, and operating life higher than 300 K_{op}). The switch robustness has greatly improved, resulting in no problem of actuating forces and tactile feel in the switch along its operational life.

There was no large change in dome shape, but the SN ratio increased 48.7 dB as a result of this optimization. The analysis and selection of the best system parameters confirmed the process estimates and resulted in a design with dramatically improved mechanical and reliability performances.

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